MACALISTER & NUTTING

Tests of an Otto Suction Gas Producer and Gas Engine

Mechanical Engineering

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TESTS OF AN OTTO SUCTION GAS PRODUCER AND GAS ENGINE

BY

Robert Norman Macalister
Harry George Dallas Nutting

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1906 H

1906
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June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT NORMAN MACALISTER and HARRY GEORGE DALLAS NUTTING

ENTITLED TESTS OF AN OTTO SUCTION GAS PRODUCER AND GAS ENGINE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

226389

1906
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TEST OF A 23 H.P. OTTO GAS ENGINE
AND SUCTION PRODUCER.

Outline.

In writing this report the following outline has been followed:

(1) Preliminary Remarks.
(2) Purpose of Test.
(3) Description of Plant.
(4) Manner of Conducting Test.
(5) Calculations.
(6) Test Data or "Log" Sheets.
(7) Summary of Data and Results.
(8) Conclusions.
(9) Index.

Preliminary Remarks.

This report contains data and results of a test made in the Mechanical Engineering Laboratory of the University of Illinois, by R. N. Macalister and H. G. D. Nutting. The test covered a period of six days beginning at 8 A.M. Monday, April

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16. and continuing to 3P.M. Saturday, April 21. Twenty four observers, mostly members of the Junior class in Mechanical Engineering recorded thedata, four men being used daily in addition to the two above mentioned. Each day one man was assigned to supervision only, to tend engine and producer and to keep watch on men and apparatus in general.

Purpose of Test.

The purpose of the test was to determine the following mechanical and thermodynamic efficiencies of the plant under ordinary commercial conditions, no attempt being made to obtain better conditions than would exist in the average power plant:

(1) Mechanical and thermodynamic efficiencies of engine.

(2) Efficiency of producer.

(3) Efficiency of plant as a whole.

(4) Utility of exhaust gas for the heating of buildings.

Description of Plant.

The plant consists of an Otto Gas Engine and Suction Producer of the following description and dimensions:

GAS ENGINE DATA.

No. Date

1. Name of engine- Otto
2. Manufactured by- Otto Gas Engine Co., Philadelphia, Penn.
3. Type- Four cycle.
4. Fuel used- Producer Gas (Suction).
5. Assumed heat in fuel- 130 B.T.U. per cu. ft.
6. H.P., builder's rating- 23
7. Floor space occupied- 55 sq. ft.
8. Weight-
9. Number of cylinders- One.
10. Diameter of fly wheels- 6 ft. 6in.

    Weight of the 2 wheels- 8160 lbs.
11. Diameter of belt pulley- 3 ft. 11 in.

    Width- 10 in.
12. Diameter of piston- 10 in. (9.997 in.)

    Length-

    Number of rings- 3
13. Stroke in inches- 19

    Displacement in cubic feet- .863
14. Clearance, cubic feet- .184 = 21.3 %
15. Length of connecting rod, inches- 47
16. R.P.M.- 226

17. Kind of Governor- Fly ball.

18. Method of Governing- Hit and miss.

19. Kind of ignition- Electric, make and break.

    a Current required-

    b Voltage-

    c Kind of plug-

    d Location- Center of head

    e Battery recommended- Edison-Leland

    f Number of cells- 6

    g Specifications of coil-

    (Magneto used- Auto-sparker)

    (Voltage- Current-)

20. Kind of valves- Poppet- Positive opening and spring closing.

21. Dimensions of valves

	Diam.-ins.	Lift- ins.
a Gas valve-	2 1/4	
b Mixture valve-	3 5/8	
c Exhaust valve-	3 3/4	

22. Means of keeping constant proportions-

    Cam shaft and air regulating valve.

23. Method of fuel feed- Suction.

29. Number of water inlets- One

    Diameter- 3/4 ins.

30. Number of water outlets- One and drain.

Diameter- 3/4 in. and 1/2 in.

31. Best rate of water feed-

32. Kind of muffler- Tank. No water.

33. Means of clearing engine of exhaust gases- None.

34. Device for starting- Compressed air.

PRODUCER DATA.

1. Kind- Otto.

2. Type- Suction.

3. Fuel- Anthracite coal.

4. Builder's rating- 50 H.P.

5. Floor space-

6. Weight-

7. Height of center line above floor-

8. Extreme outside diameter-

9. Grate area- 1.58 sq. ft.

10. Builder's rated H.P. per sq. ft.- 31.6

11. Water heating surface- 10.86 sq. ft.

12. " " " per builder's H.P.- .217 sq. ft.

13. Weight of anthracite coal producer holds- 1018 lbs.

14. Thickness of fire brick lining- 8 in.

SCRUBBER.

1. Type- Coke and water spray- Water sealed.
2. Height-
3. Diameter-
4. Cubic contents-
5. Water inlet drain-
6. Best amount of water-

The operation of theplant is as follows: Referring to Plate I, a fire is built on the grate D, and the producer filled with anthracite pea coal to the charging door C. A blast is blown into the air tight ash pit E, by means of the hand blower G, and the fire is blown up until good gas is available at a gas cock in the outlet pipe, H. The valve, J, is then closed and thewater seal valve, K, opened, thus allowing the gas to pass through the scrubber, L, which is filled with coke over which water trickles. The water going down meets the up going gas and in this way cleans it. The gas then passes out at the top through the pipe, M, into a small storage tank, N, which is large enough to hold two or three charges of gas. From N the gas goes to the engine, P, through the valve R. After the engine is started, the fan, G, is stopped and the producer gets its draft from the suction of the engine, air going in at S, mixing with the steam from the water jacket, F,

and passing through the pipe, T, into the ash pit and up through the grate. When the engine is shut down for a time the gas is turned through the stack, U, on the engine side of the scrubber, or through the stack, V, on the producer side, depending upon the length of time it is not running.

Plate 8 is a general view of the plant and apparatus looking east. A is the producer, C the scrubber, B the engine, D the heater, which is not ordinarily a part of the plant, K a prony brake acting on the scale L, H the air pressure tank, G the air meter, Q the air regulating valve, M the chemistry apparatus, T the vaporizer water supply can, O the gas meter, P a tachometer, E theair compressor pumping into receiver N.

The engine is of the four cycle type andrated at 23 H.P. It is equipped with two extra heavy fly wheels to carry a lighting load with good regulation. Plate No. 2 shows a general design of engine. A is the gas inlet; B the gas valve box; C the mixture valve; and D the exhaust valve. E is the sparker actuating rod, F the governor, H the valve cams for mixture and exhaust valves, K is the cam for operating the gas valve.

Manner of Conducting Test.

The plant was first carefully examined for physical defects, both engine and producer being taken apart where this

was necessary. Measurements were made of the different parts, the cylinder clearance being determined by the water method. A preliminary run of a week was made previous to the test in order to get the plant into good running condition. During this time the apparatus was adjusted and calibrated, no attempt being made to record test data.

The test was started Monday at 8 A.M. under the following conditions: the coal magazine was filled to the top, the ash pit cleaned out, the vaporizer pan and ash pit floor filled with water, and readings were taken of all meters, thermometers, and other apparatus. At 3P.M. the following Saturday the test was closed under exactly the same conditions. The daily runs were about nine hours long and were started and stopped under the above conditions except that the ash was sometimes removed a short time before the stopping time. Indicator cards were taken every twenty minutes. Revolutions, explosions and brake pull were read every twenty minutes. Thermometers were read every half hour, and meters every hour. The heat value of the gas was taken with a Junker's Calorimeter every half hour, the other gas analysis being kept in operation continuously. Water was weighed in tanks on Buffalo scales except in case of scrubber water which was measured by a meter. It was intended to measure the air and gas used by means of meters but these proved defective in operation and it

became necessary to calculate volumes of air and gas from chemical analyses and the amount of carbon gasified. Coal and ash were weighed on Buffalo scales as delivered, a sample being taken from each lot for analysis. The work of the engine was absorbed by a Prony brake on an extension of the engine shaft. The gas analysis apparatus consisted of a Junker Calorimeter and an Orsat apparatus in connection with a Hempel explosion pipette. During the first three days the directions of the Otto Gas Engine Co. were followed as to the operation of the producer, i.e., the fire was filled, poked and cleaned every two or three hours. On the three following days the producer was kept full of coal as before, but was poked from above only two or three times during the day and the ash pit and fire doors were opened but once a day for the removal of ashes and cleaning of the fire, thus allowing the formation of an ash bed above the grate. All meters, scales, instruments and other apparatus used in this test, except thermometers, were calibrated, and their limits of error determined.

Methods of Calculating Results.

The methods of calculating results shown on Result Sheets were taken from the following:

"Working Details of a Gas Engine Test" by R. H. Fernald. A. S. M. E. Paper No. 950.

A. S. M. E. Paper No. 081. Vol. XXVII.

"Producer Gas and Gas Producers" by Samuel S. Wyer.

"Gas Engine Design" by Charles E. Lucke.

In addition to these some reference was had to

"Gas Engine and Producer Gas Plants" by R. E. Mathot,

"Suction Gas" by Oswald H. Haenssgen,

Catalogs of Morgan Gas Producer Co., and the

R. D. Wood and Co.,

" Hempel's Gas Analysis."

Conclusions.

From the results of this test as shown in the tables, the following conclusions may be drawn:

(1) The average mechanical and thermodynamic efficiency of the engine is fairly good.

(2) The thermodynamic efficiency of the producer is low.

(3) From (2) it follows that the efficiency of the plant is low.

(4) As seen from the result sheet about 11000 lbs. of water was heated per day up to 153°, or about 1375 lbs. per hour. Allowing a drop in the radiators of 30°, this would render available 30 x 1375 = 41250 B.T.U. per hour for heating, which would heat a room of about 10000 cu. ft. with 84 sq. ft. of glass surface, from 0° to 70°.

(5) The coal consumption per B.H.P. hour is higher than that usually guaranteed by builders of gas producers.

(6) The best results were obtained by themethod of firing adopted during the last three days of the test, and not by the method recommended by the builders.

(7) The best results would be obtained by having a bed of ashes on the grate, say about six inches, thus obtaining the same effect as given by thethick ash bed of a soft coal producer.

(8) The cooling water should leave the jacket at about 160° to 170° F. for best efficiency. Water at higher temperature than this has a tendency to carbonize the cylinder oil and to form scale in the cylinder jacket.

Observation of conditions during the test lead to the following conclusions:

(1) That there should be no connection between the exhaust pipe from engine and the chimney pipes from producer. The present construction allowed back firing of gas in producer and caused gas to be blown out into producer room, vitiating the atmosphere.

(2) That meters both water and gas even when carefully calibrated are not to be depended upon for accurate results.

(3) That the mixture valve of this engine is set too near the crank end, and if it should stick would be hit by the pis-

ton on the compression stroke. It would be better to have positively actuated valves rather than the present spring closing type.

(4) The low power developed by the engine was partly caused by high back pressure due to the heater and to the increased number of bends in the exhaust pipe.

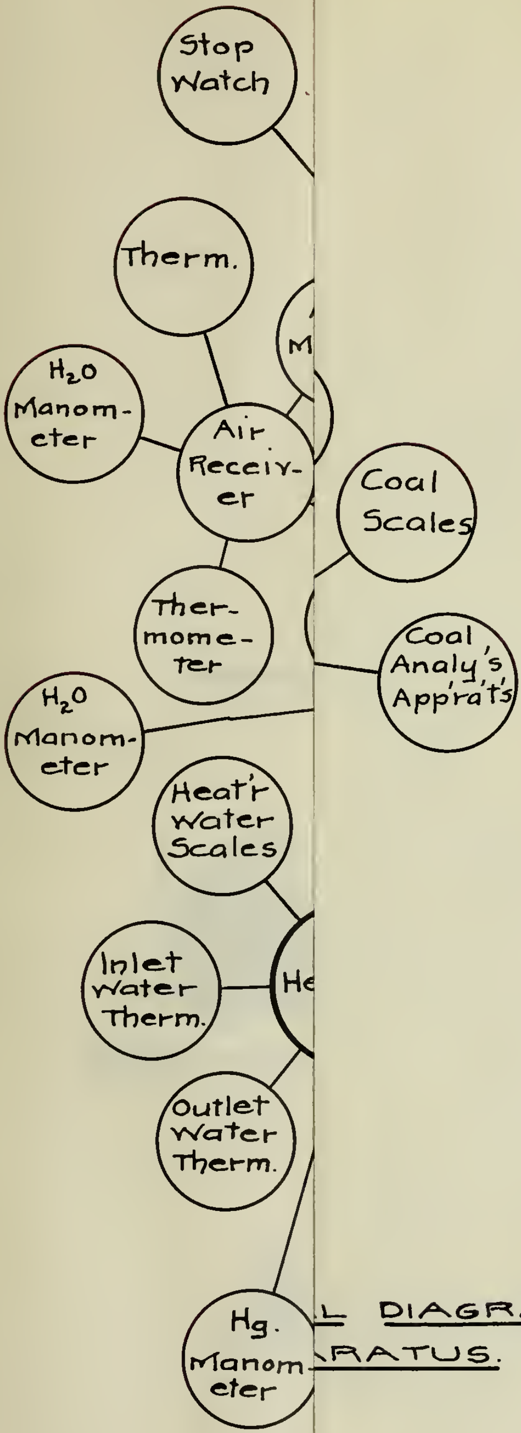
(5) Failure to start an engine of this type may generally be traced to one of three causes:

a- poor compression.

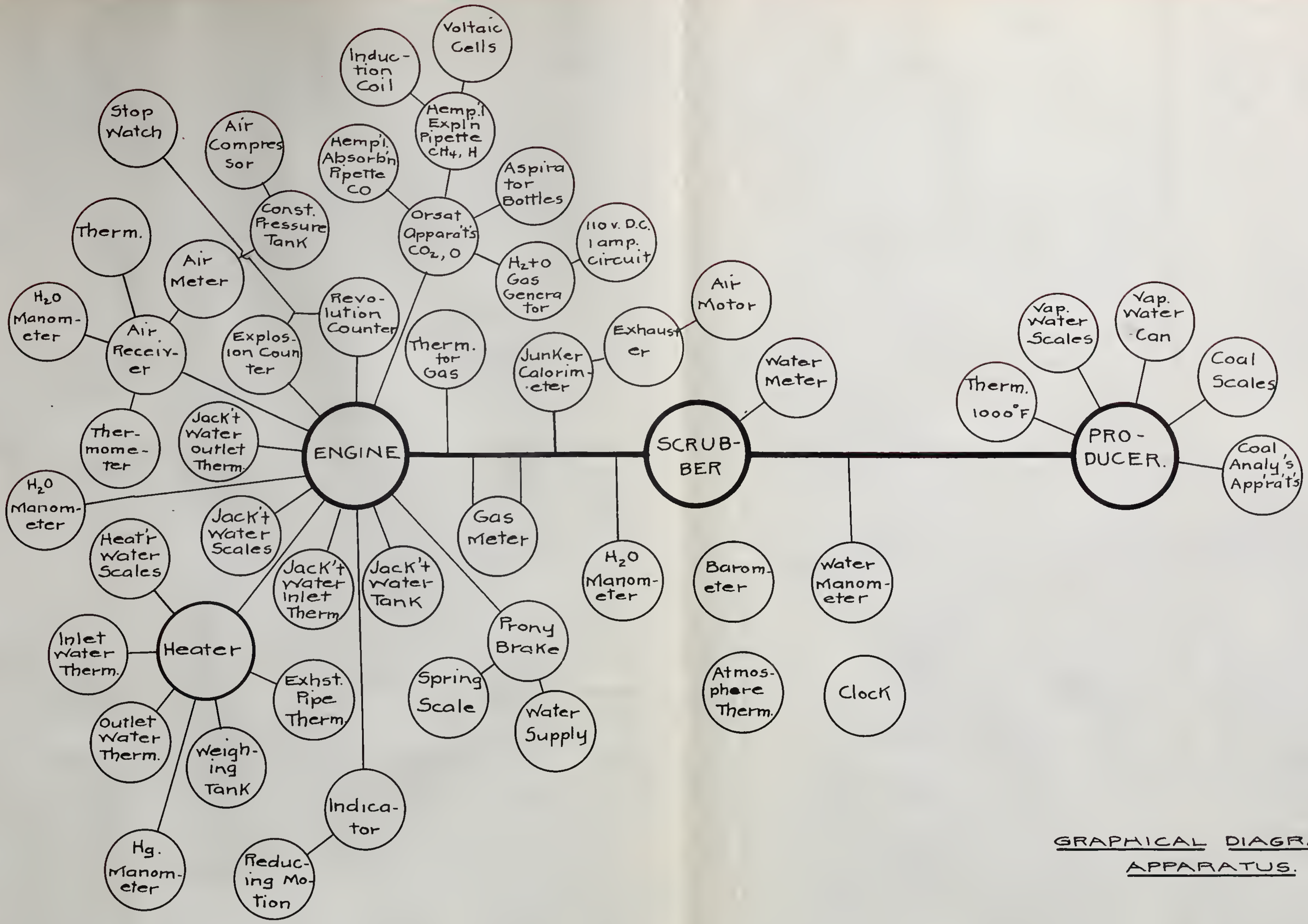
b- poor gas.

c- defective sparker.

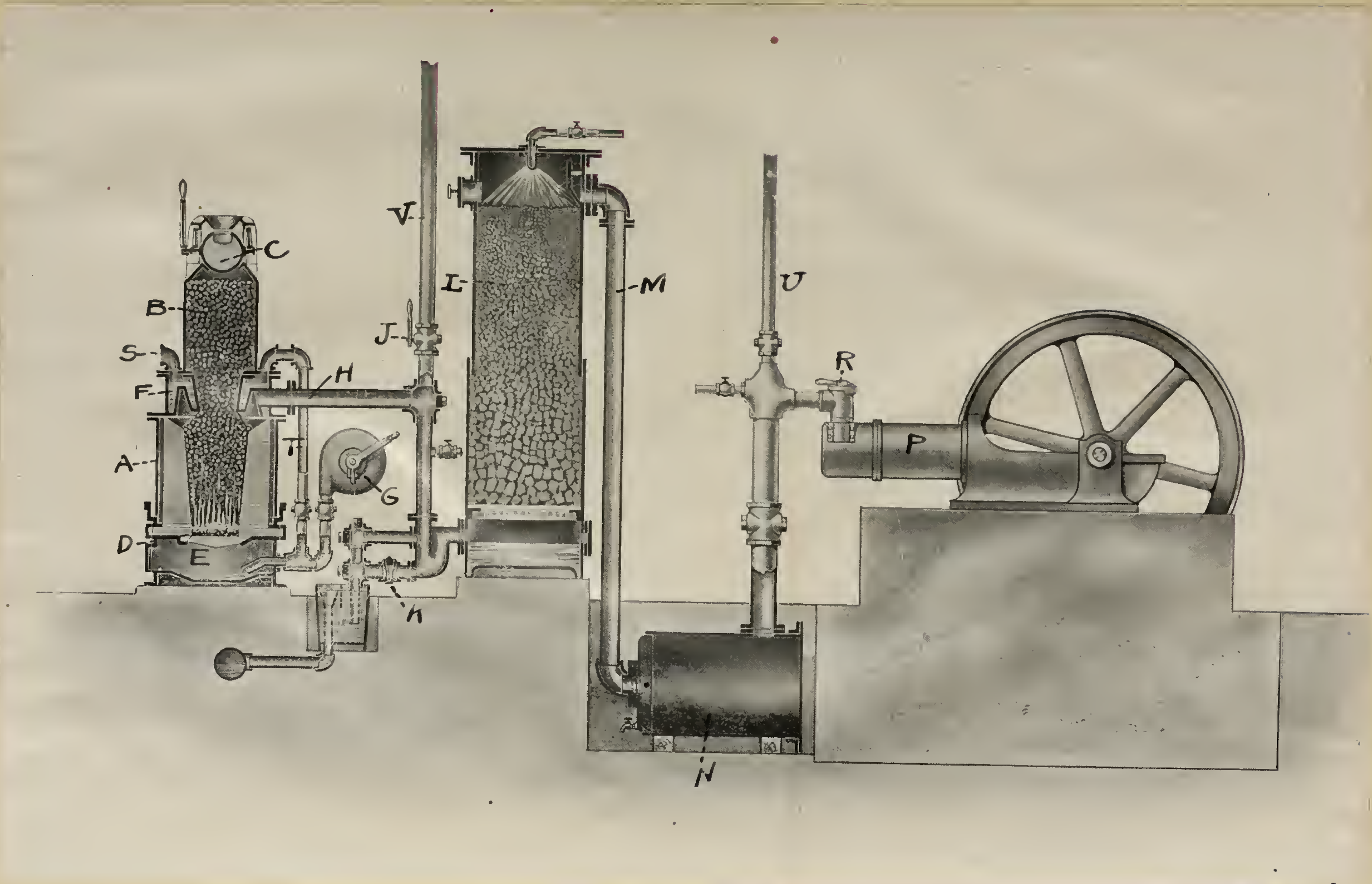
(6) In a test of this kind a good gas analysis is of utmost importance.


Stop Watch
Therm.
H_2O Manometer
Air Receiver
M
Coal Scales
Thermometer
Coal Analy's Appr'ats
H_2O Manometer
Heat'r Water Scales
Inlet Water Therm.
He
Outlet Water Therm.
Hg. Manometer

L DIAGRAM of
RATUS.


Voltaic Cells
Induction Coil
Hemp'l Expl'n Pipette CH_4, H
Stop Watch
Air Compressor
Hemp'l. Absorb'n Pipette CO
Aspirator Bottles
Const. Pressure Tank
Orsat Apparat's CO_2, O
110 v. D.C. 1 amp. circuit
Therm.
Air Meter
H_2 to Gas Generator
Air Motor
H_2O Manometer
Revolution Counter
Air Receiver
Explosion Counter
Therm. for Gas
Junker Calorimeter
Exhauster
Water Meter
Vap. Water Scales
Vap. Water Can
Coal Scales
Therm. 1000°F
Thermometer
Jack't Water outlet Therm.
ENGINE
SCRUBBER
PRODUCER.
Coal Analy's Appra'ts
H_2O Manometer
Jack't Water Scales
Gas Meter
Heat'r Water Scales
Jack't Water Inlet Therm.
Jack't Water Tank
H_2O Manometer
Barometer
Water Manometer
Prony Brake
Inlet Water Therm.
Heater
Exhst. Pipe Therm.
Spring Scale
Water Supply
Atmosphere Therm.
Clock
Outlet Water Therm.
Weighing Tank
Indicator
Hg. Manometer
Reducing Motion

GRAPHICAL DIAGRAM of APPARATUS.


V
C
L
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J
S
H
R
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T
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N

Diagram of Plant.

PLATE 1.

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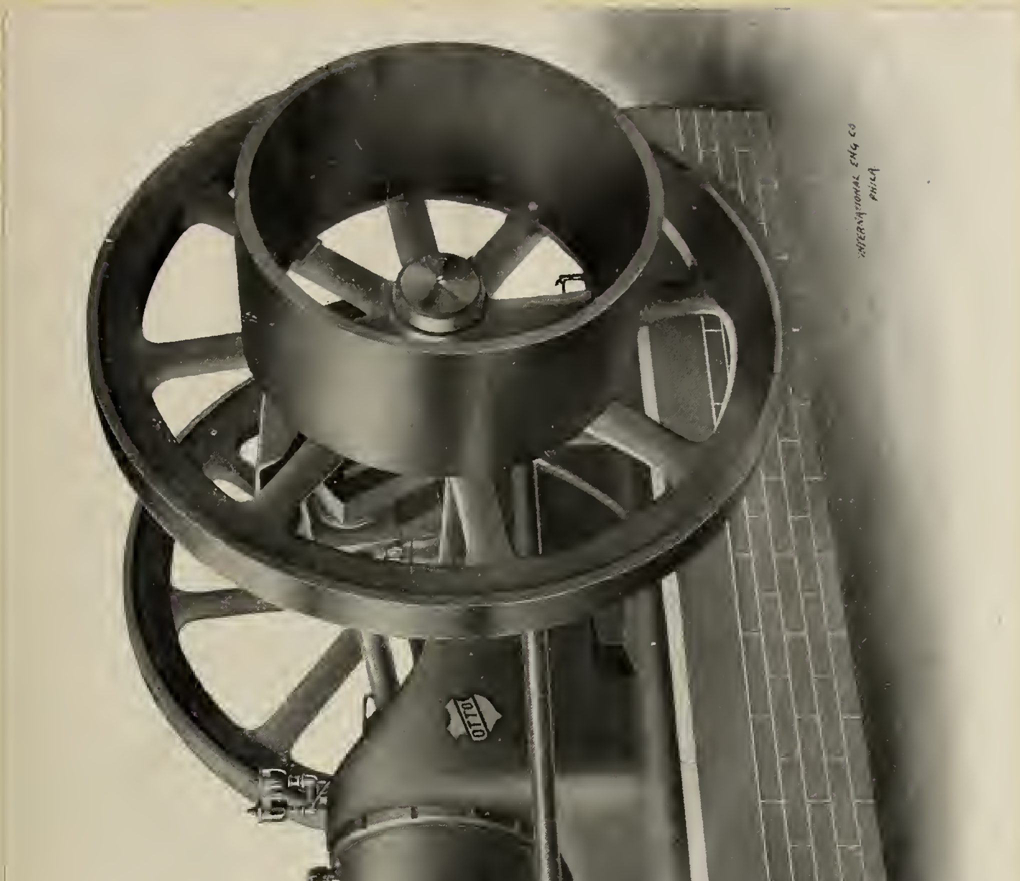
A
B
C
D
E
F
OTTO
INTERNATIONAL ENG CO
PHILA

General View of Engine.

PLATE 2.

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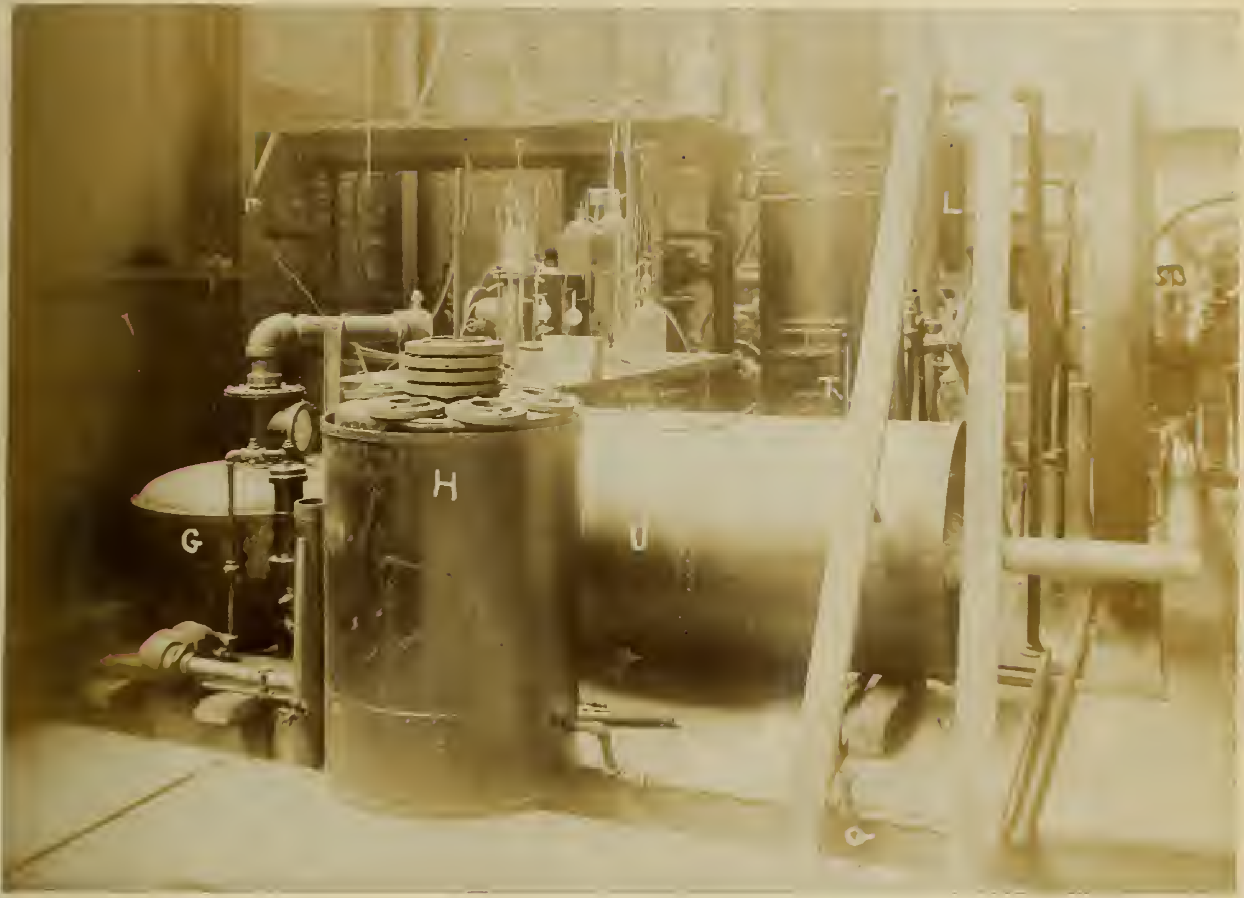

View of Air Pressure-tanks and Meter.

PLATE 3.

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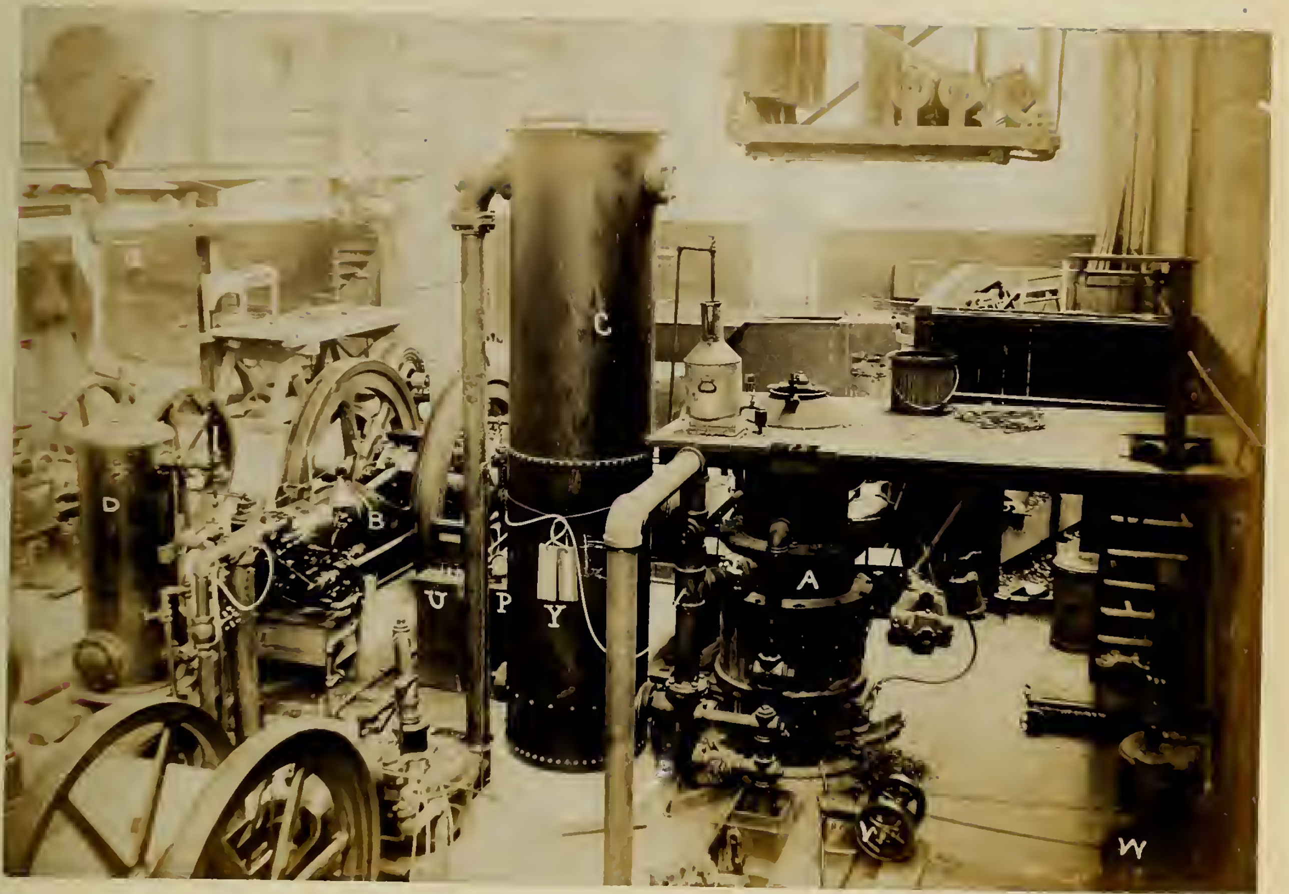

General View of Plant looking West.

PLATE 4.

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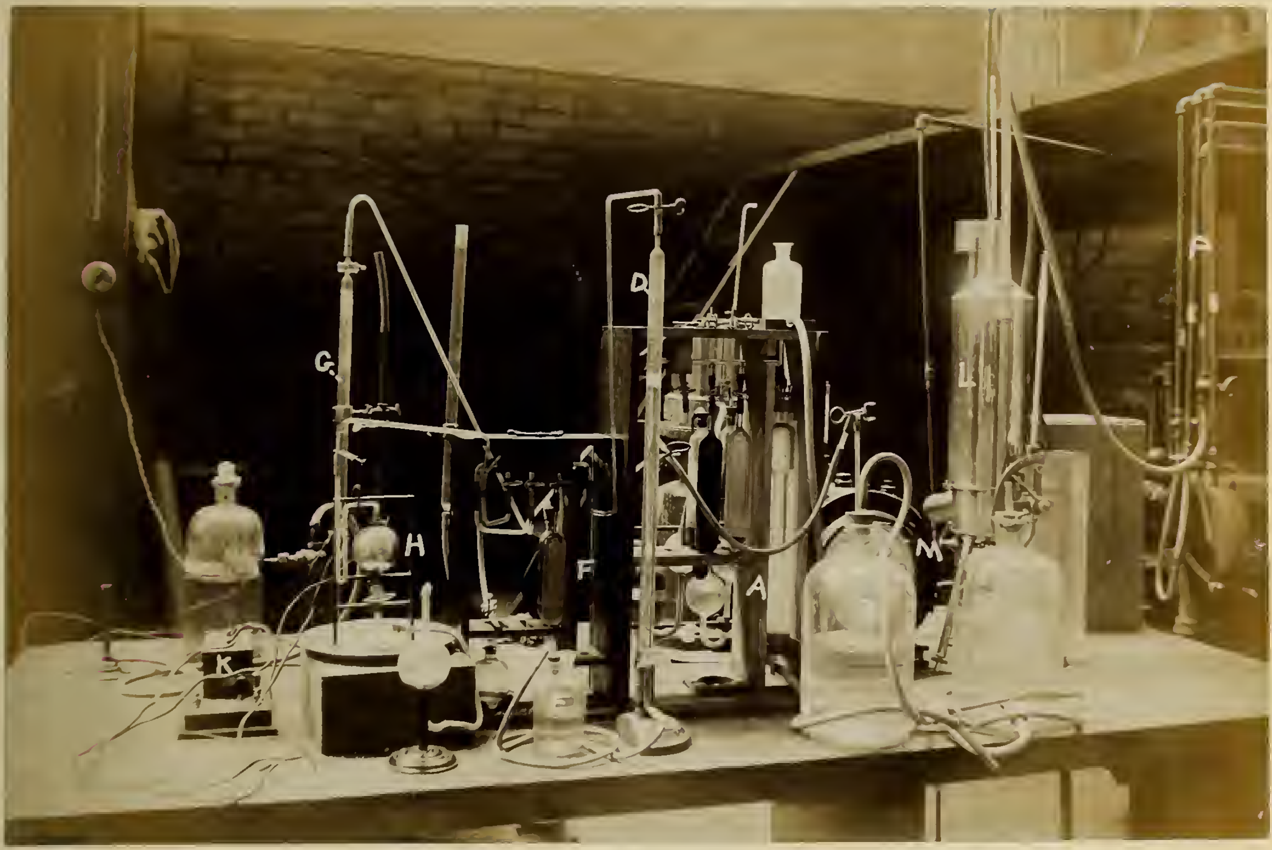

Gas Analysis Apparatus.

PLATE 5.

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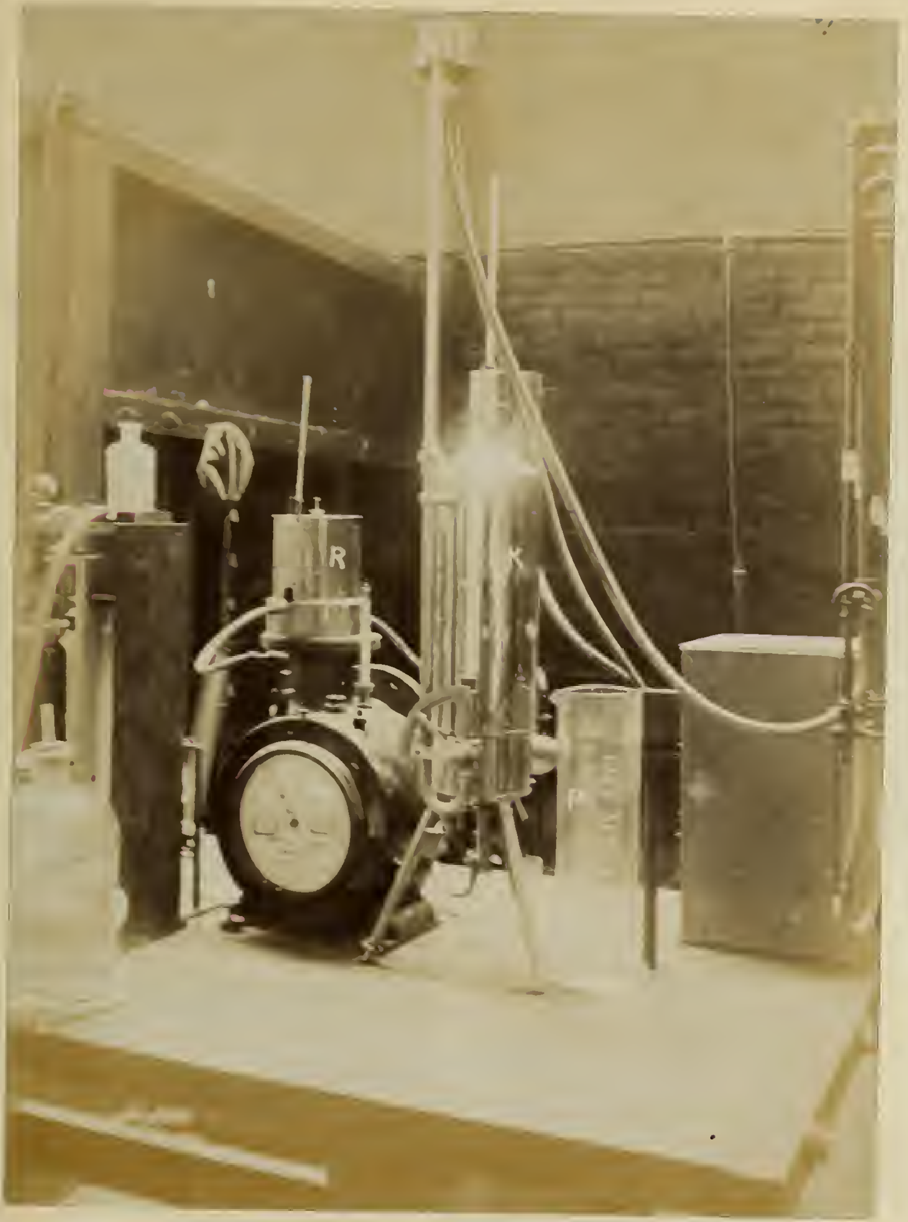

Junker's Calorimeter

PLATE 6.

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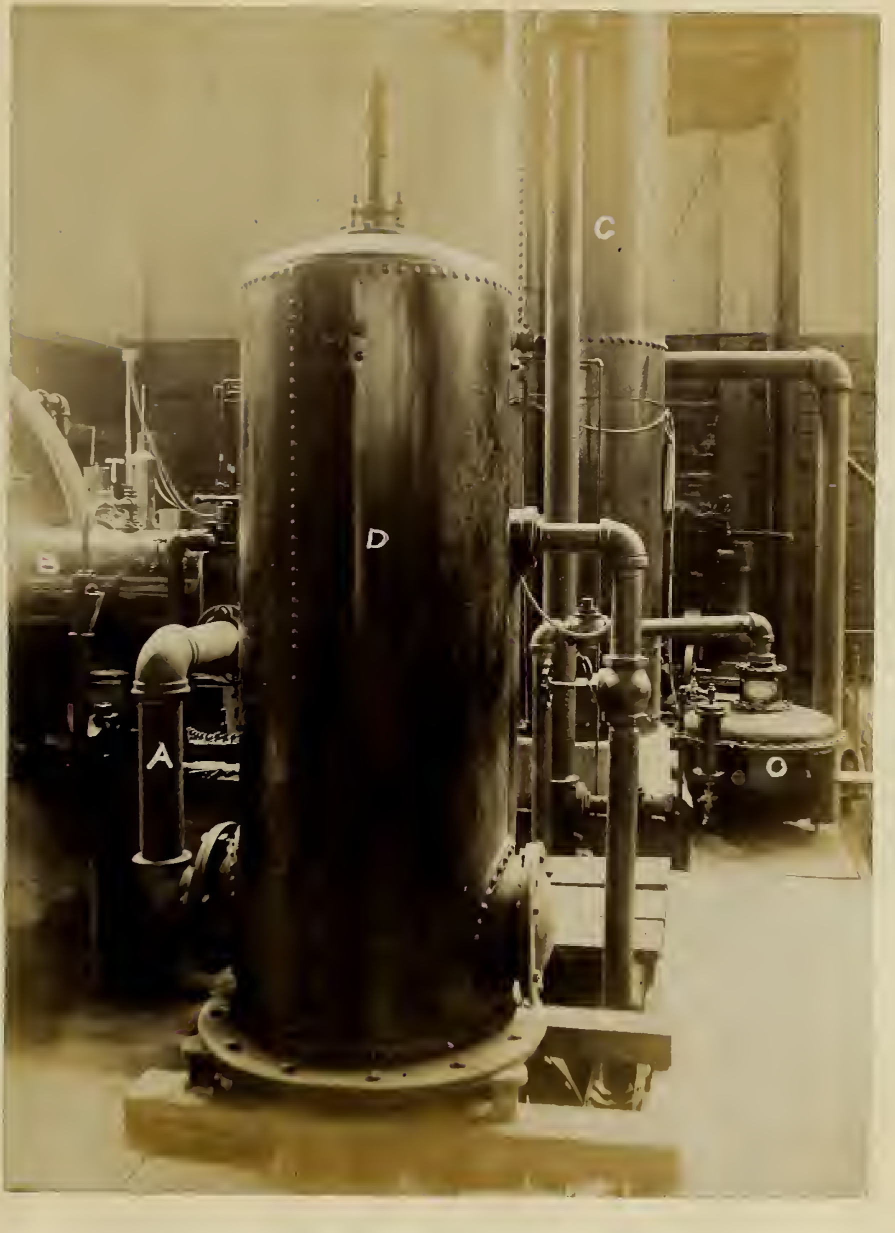

Heater, and Gas Meter.

PLATE 7.

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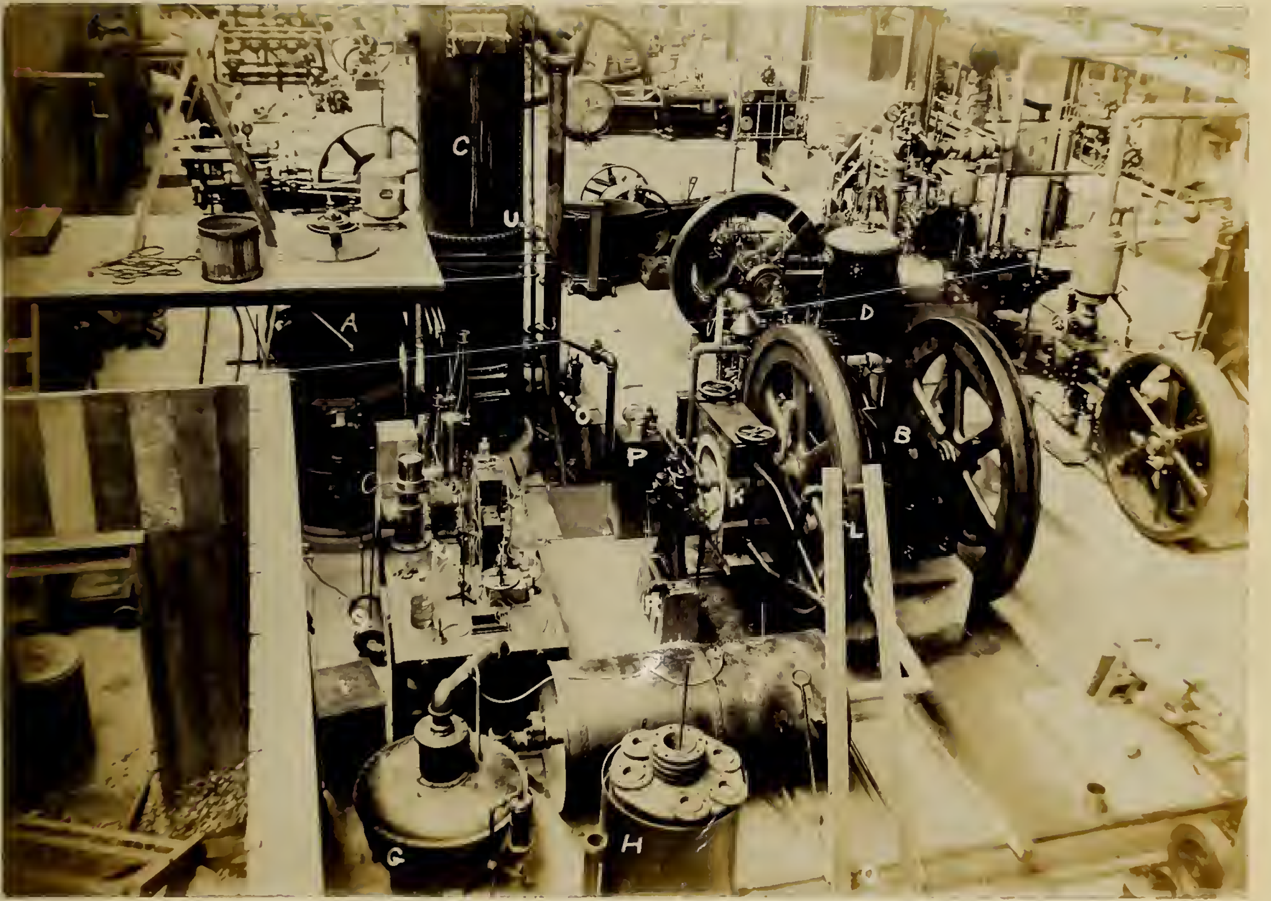
C
U
A
D
O
B
P
K
L
G
H

General View of Plant looking East.

PLATE 8.

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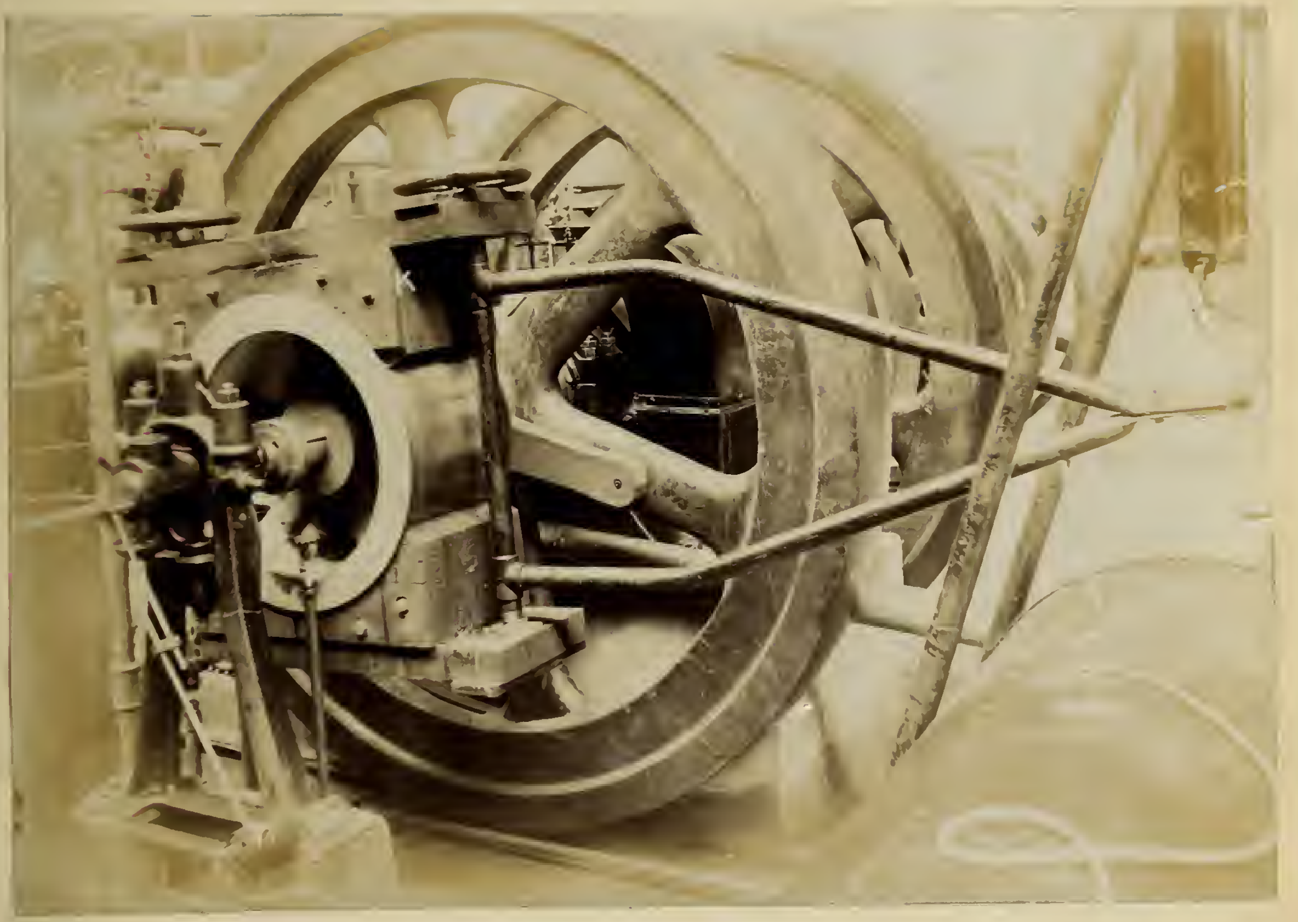

Prony Brake and Revolution Counter.

PLATE 9.

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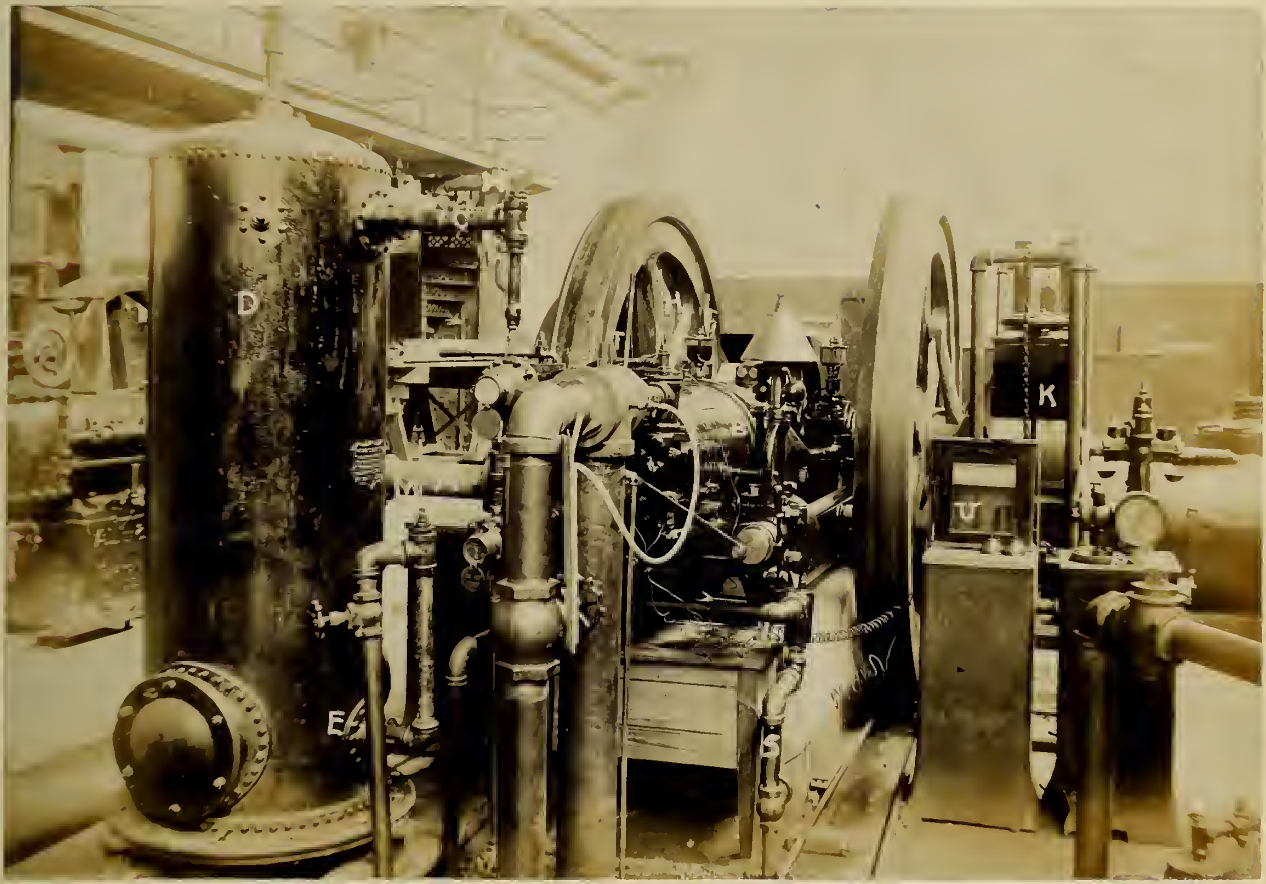

Front View of Engine showing Heater,
Explosion Counter, and Tachometer.

PLATE 10.

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SU

No.	Item.			Totals	Average
1	Date, Apr., 190		1.	Totals	Average
2	Length of Tes		7.	51.5	
3	Time intervals		0.		
4		Total	0.		
5	Rev.	R.P.M	2.		215.
6	and	Tota	0.		
7	Explos.	E.P.M	6.		107.
8		Rati	2.		
8.5		Tem	4.		153.7
9		Wgt.	7.	44179.	7350.
10	Jacket	Wgt.	2.		858.
11		Temp	4.5		94.3
12	Water	Max.			
13		Heat	0.		81000.
13.5		Heat	0.	4,154600.	
14		Wgt.	5.	16425.	2740.
15	Heater	Wgt.	9.		316.
16		Temp	0.5		91.1
17	Water	Hea	0.		28800.
17.5		Heat	0.	1,493,000.	
18		Total	00.		
19		Per h	0.		2277.
20	Air.	Temp	0.		
21		Wgt.	.076		.076
22		Max.			
23		Spec	.2375		.2375
			.1691		.1691
24	Barometer, ins		29.22		
25		Total	0.		
26	Fuel	Per h	0.		1716.
27		Temp	5.		75.2
28	Gas	Wgt.	.0667		.0694
29		Max.	.567		.4875
30		Spec	.0203		.0204
31		Anal			
32		C	5.2		6.7

SUMMARY and RESULTS.

No.	Item.									
1	Date, Apr., 1906		16.	17.	18.	19.	20.	21.	Totals	Average
2	Length of Test, hrs.		8.6	9.	8.6	9.0	9.3	7.	51.5	
3	Time intervals, min.		20.	20.	20.	20.	20.	20.		
4		Total rev. for day,	111456.	115020.	110940.	117180.	120528.	89040.		
5	Rev.	R.P.M. (mean)	216.	213.	215.	217.	216.	212.		215.
6	and	Total explos. for day,	54713.	57240.	55212.	58860.	60264.	44520.		
7	Explos.	E.P.M. (mean)	108.	106.	107.	109.	108.	106.		107.
8		Ratio, R.P.M. to E.P.M.	2.	2.	2.	2.	2.	2.		
8.5		Temp. leaving, F°	153.	161.	151.	156.	147.	154.		153.7
9		Wgt. for day, lbs.	* 7200.	7223.	7336.	7256.	8907.	6257.	44179.	7350.
10	Jacket	Wgt. per hr., lbs.	* 835.	803.	852.	806.	960.	892.		858.
11		Temp. range, F°	94.	101.5	91.	96.5	88.3	94.5		94.3
12	Water	Max. vel., ft. per sec.								
13		Heat absorbed per hr. B.t.u.	78500.	81700.	77600.	77800.	84850.	84300.		81000.
13.5		Heat absorbed per day, B.t.u.	674500.	735000.	668500.	698500.	788000.	590100.	4,154600.	
14		Wgt. for day, lbs.	* 2500.	3185.	2790.	2482.	3653.	1815.	16425.	2740.
15	Heater	Wgt. per hr., lbs.	* 290.	354.	325.	276.	392.	259.		316.
16		Temp. range, F°	94.	89.9	91.	* 90.5	* 90.5	* 90.5		91.1
17	Water	Heat absorbed per hr., B.t.u.	* 27250.	31750.	29600.	* 24950.	* 35450.	* 23400.		28800.
17.5		Heat absorbed per day, B.t.u.	* 234500.	286000.	255000.	* 224500.	* 329000.	* 164000.	1,493,000.	
18		Total for day, cu. ft. st'd.	23730.	22500.	14650.	22150.	21500.	13500.		
19		Per hr., cu. ft., st'd.	2760.	2500.	1700.	2460.	2315.	1930.		2277.
20	Air.	Temp., F°	66.	72.7	75.	70.	70.	70.		
21		Wgt. per cu. ft., st'd	.076	.076	.076	.076	.076	.076		.076
22		Max. vel., ft. per sec.								
23		Specific Heat, C_p	.2375	.2375	.2375	.2375	.2375	.2375		.2375
		" " C_v	.1691	.1691	.1691	.1691	.1691	.1691		.1691
24	Barometer, ins. of mercury.		29.71	29.7	29.56	29.46	29.39	29.22		
25		Total for day, cu. ft., st'd.	19000.	18900.	12620.	17400.	13100.	8280.		
26	Fuel	Per hr., cu. ft., st'd.	2200.	2100.	1470.	1935.	1410.	1180.		1716.
27		Temp., F°	70.	77.2	79.	* 75.	* 75.	* 75.		75.2
28	Gas	Wgt. per cu. ft. st'd	.0718	.0712	.0718	.0670	.0680	.0667		.0694
29		Max. vel., ft. per sec.								
30		Specific heats, C_p and C_v	.386 .0201	.415 .0202	.404 .0204	.607 .0200	.546 .0206	.567 .0203		.4875 .0204
31		Analysis by vol. %								
32		CO_2	6.3	6.5	7.9	5.6	8.5	5.2		6.7

* Estimated.

	Date, Apr., 1906		21	Total	Average
33	St'd.	CO	17.8		19.0
34	Fuel	O	.4		.8
35	Gas	CH	10.6		8.0
36	(continued)	H	8.4		6.8
37		N	57.6		58.7
38		B.t.u	128.9		120.3
39		Temp.,			
40		Wgt. p			
41	St'd	Max.			
42	Mixture.	Spec			
43	(Air,				
44	Gas,	Anal			
45	and	CC			
46	Neutrals)	CC			
47		C			
48		CH			
49					
50					
51		B.t.u			
52		Per ft	2970.		3839.
53		Wgt.	.0850		.0852
54	St'd	Spec	.239		.239
55	Exhaust	Anal			
56		CO	15.4		15.7
57	Gases	C	1.1		1.2
58			83.5		.83
59		Temp.			
60		Temp.*	140.		138.8
61	Valve in-	Gas	Open		
62	dex reading.	Air.	3.		
63	Value of n in				
64	Pressures	At en			
65	from	Max.			
66	Indicator	At enc			
67	Cards.	Expar			
68	lbs. per sq. in.	M.E.			

#

	Date, Apr., 1906		16.	17.	18.	19.	20.	21	Total	Average
33	St'd.	CO	20.5	17.9	16.7	22.	18.9	17.8		19.0
34	Fuel	O	.85	.5	.65	.8	1.5	.4		.8
35	Gas	CH_4	6.5	7.0	7.2	5.4	11.0	10.6		8.0
36	(continued)	H	3.8	4.7	4.3	10.9	8.4	8.4		6.8
37		N	62.05	63.4	63.25	55.3	51.5	57.6		58.7
38		B.t.u. per cu. ft. by calorimeter (high)	116.2	116.2	110.0	120.8	129.8	128.9		120.3
39		Temp., F°								
40		Wgt. per cu. ft.								
41	St'd	Max. vel., ft. per sec.								
42	Mixture.	Specific heats, C_p								
43	(Air,	C_v								
44	Gas,	Analysis by vol. %								
45	and	CO_2								
46	Neutrals)	CO								
47		O								
48		CH_4								
49		H								
50		N								
51		B.t.u. per cu. ft.								
52		Per hr., cu. ft. #	4690.	4425.	3090.	4180.	3680.	2970.		3839.
53		Wgt. per cu. ft.	.0849	.0848	.0852	.0855	.0859	.0850		.0852
54	St'd	Specific heat, C_p	.239	.239	.239	.239	.239	.239		.239
55	Exhaust	Analysis by vol. %								
56		CO_2	15.05	15.4	15.2	16.0	17.3	15.4		15.7
57	Gases	O	2.05	.9	1.8	.9	.7	1.1		1.2
58		N	82.9	83.7	83.0	83.1	82.0	83.5		.83
59		Temp. at exhaust valve, F°								
60		Temp. after leaving heater, F°	133.	140.5	139.0	* 140.	* 140.	* 140.		138.8
61	Valve in-	Gas	Open	Open	Open	Open	Open	Open		
62	dex read-	Air.	3	3.	3.	3.	3.	3.		
	ing.									
63	Value of n in PV^n = Const.									
64	Pressures	At end of compression								
65	from	Max.								
66	Indicator	At end of expansion,								
67	Cards.	Expan. carried to end of stroke								
68	lbs. per sq. in.	M.E.P.								

Products of Comb. + Excess Air.

	Date, Apr.,		21	Totals	Average
68.5	Ratios	Ai	1.63		1.34
69		Mix			
70		Str			
71		Tot			
72		Ma			
73		Max			
74	Value of R in F				
75	Temp. at compr				
76	Max. Temp., F°				
77	Energies	Av.	16.2		16.7
78		B.H	113.0	858.3	143.1
79		B.t.	50.		42383.
80		I.H.	23.7		22.9
81		B.t.	300.		58333.
82		Ga	60.		80.6
83		B.t	000.		205000.
84		Hea			
85		Hea			
86		Hea			
87		I.H.	7.5		6.25
88	Throttling, cu.ft				
89	Throttling, %				
90	Work gained by				
91	Efficiencies.	Mec	.684		.73
92		Ther	.271		.206
93		Ther	.203		.172
94		Ther	.396		.285
95		Ther			
96		The	.75		.659
97		The			
98		The			
99	St'd Gas per hr.	Ga			
100		Ga	73.0		103.7

Calculated fro

	Date, Apr.,		16.	17.	18.	19.	20	21	Totals	Average
68.5	Ratios	Air to gas #	1.16	1.19	1.16	1.27	1.64	1.63		1.34
69		Mixture to neutrals								
70		Stroke to expans'n								
71		Total vol. to clearance vol.		5.7						
72		Max. press. to M.E.P.								
73		Max. press. to compression.								
74	Value of R in PV=RT									
75	Temp. at compression, F°									
76	Max. Temp, F°									
77	Energies	Av. B.H.P.	15.4	16.7	16.2	17.6	17.8	16.2		16.7
78		B.H.P. hrs.	132.3	150.	139.	158.0	166.0	113.0	858.3	143.1
79		B.t.u. per hr. equiv. to B.H.P.	39200.	42500.	41250.	44800.	45300.	41250.		42383.
80		I.H.P.	22.0	23.5	21.	23.7	23.6	23.7		22.9
81		B.t.u. per hr. equiv. to I.H.P.	56000.	59800.	53500.	60300.	60100.	60300.		58333.
82		Gas H.P.	101.	96.	63.5	91.	72.	60.		80.6
83		B.t.u. per hr. equiv. to G.H.P.	256000.	244100.	161700.	231900.	183000.	152000.		205000.
84		Heat supplied per hr. from card, B.t.u.								
85		Heat extracted per hr. from card, B.t.u.								
86		Heat extracted per hr. by observ'n, B.t.u.								
87		I.H.P.–B.H.P.	6.6	6.8	4.8	6.1	5.8	7.5		6.25
88	Throttling, cu. ft.									
89	Throttling, %									
90	Work gained by complete expansion, ft. lbs.									
91	Efficiencies.	Mech. Eff. of Engine	.70	.712	.772	.743	.755	.684		.73
92		Thermal for B.H.P. (of Engine)	.153	.174	.255	.193	.248	.271		.206
93		Thermal for B.H.P. (of Plant)	.099	.109	.144	.137	.163	.203		.172
94		Thermal for I.H.P. (of Engine)	.219	.245	.331	.26	.328	.396		.285
95		Thermal for I.H.P. (of Plant)								
96		Thermal Eff. (of Prod. and Scrubr; Cold)	.647	.628	.564	.710	.66	.75		.659
97		Thermal Eff. (b)								
98		Thermal Eff. (c)								
99	St'd Gas per hr.	Gas per I.H.P., cu. ft.								
100		Gas per B.H.P., cu. ft.	143.0	126.0	91.0	110.0	79.0	73.0		103.7

Calculated from Gas Analysis. Excess not included.

PROD

	Date, Apr.,		21.	Totals	Average
101	Temp. Gas leaving Pr		525.		
102	Outside items charged against Producer Plant.	Total ste	119.5		
103		Steam p	17.1		
104		Equiv. ir			
105		Equiv. in			
106		Equiv. in			
107		Av. H.P. to			
108		Total scr	11750.	86300.	
109		Water pe			
110		Water pe			
111	Fuel consumed in Producer (including standby)	Proxima			
112		Moist	2.16		
113		Ash,	9.54		
114		Volat	5.04		
115		Fixe	83.26		
116		Sulp	.37		
117		Mois	.07		
118		Total co	132.	1439.	
119		Total dry	129.	1400.	
120		Refuse	18.2	122.9	
121		Total ref	23.5	299.	
122		Total co	116.5	1269.	
123		Coal per	18.9		27.7
124		Dry Co	18.4		27
125		Combusi	16.7		24.5
126		Equiv. c			
127		Equiv. d			
128		Equiv. c			
129	B.t.u. in fuel. (includes standby)	Per lb. co	3721.		
130		Per lb. d			
131		Per lb. co			
132		From co	51000.		
133		From dry			
134		From co			
135	Fuel per sq. ft. fuel bed per hr.	Coal as	11.95		
136		Dry coa			
137		Combus			

PRODUCER

		Date, Apr.,	16.	17.	18.	19.	20.	21.	Totals	Average
101		Temp. Gas leaving Producer, F°	472.	488.	476.	*525.	*525.	*525.		
102		Total steam used by producer, lbs.	155.	179.	185.2	158.	173.	119.5		
103	Outside	Steam per hr, lbs.	18.	19.9	21.6	17.6	18.6	17.1		
104	items	Equiv. in lbs. coal per hr.,								
105	charged	Equiv. in dry coal per hr., lbs.								
106	against	Equiv. in combust. per hr. lbs.								
107	Producer	Av. H.P. to drive auxiliaries.								
108	Plant.	Total scrubber water, lbs *	14400.	15100.	14400.	15100.	15600.	11750.	86300.	
109		Water per B.H.P. hr. of plant, lbs.								
110		Water per 1000 cu.ft. gas., lbs.								
111		Proximate Analysis								
112		Moisture, %	2.16	2.16	2.16	2.16	2.16	2.16		
113		Ash, %	9.54	9.54	9.54	9.54	9.54	9.54		
114	Fuel	Volatile, %	5.04	5.04	5.04	5.04	5.04	5.04		
115	consumed	Fixed Carbon, %	83.26	83.26	83.26	83.26	83.26	83.26		
116	in	Sulphur, %	.37	.37	.37	.37	.37	.37		
117	Producer	Moisture, Air drying, %	.07	.07	.07	.07	.07	.07		
118	(including	Total coal consumed, lbs.	256.	291.5	278.5	239.0	242.0	132.	1439.	
119	standby)	Total dry coal consumed, lbs.	250.	284.0	272.0	234.0	236.0	129.	1400.	
120		Refuse from dry coal, %	14.7	27.5	36.3	13.0	13.2	18.2	122.9	
121		Total refuse from coal, lbs. (Dry)	36.8	78.2	99.	30.3	31.2	23.5	299.	
122		Total combustible, lbs.	226.0	257.3	246.	211.0	214.	116.5	1269.	
123		Coal per hr. as fired, lbs.	29.8	32.4	32.4	26.6	26.0	18.9		27.7
124		Dry Coal per hr., lbs.	29.1	31.6	31.6	26.0	25.4	18.4		27
125		Combustible per hr., lbs.	26.3	28.6	28.6	23.5	23.0	16.7		24.5
126		Equiv. coal per hr., lbs.								
127		Equiv. dry coal per hr., lbs.								
128		Equiv. combustible per hr., lbs.								
129		Per lb. coal as fired, B.t.u.	13721.0	13721.0	13721.	13721.	13721.	13721.		
130		Per lb. dry coal, B.t.u.								
131	B.t.u. in	Per lb. combustible, B.t.u.								
132	fuel.	From coal as fired per hr., B.t.u.	396000.	420000.	482000.	353500.	345500.	251000.		
133	(includes	From dry coal per hr., B.t.u.								
134	standby)	From combustible per hr., B.t.u.								
135	Fuel per	Coal as fired, lbs.	18.8	20.5	20.5	16.8	16.5	11.95		
136	sq.ft. fuel	Dry coal, lbs.								
137	bed per hr.	Combustible, lbs.								

* Approximate

	Date, Apr.		21.	Totals	Average
138	St'd gas produced, cu. ft.	Per lb. c	77.1		72.8
139		Per lb. a			
140		Per lb. c			
141		Per lb. e			
142		Per lb. e			
143	Coal per H.P. hr.	Per B.H.	.945		1.43
144		Equiv. p	1.17		1.66
145	Cost of Coal	Cost pe	5.35		5.35
146		Cost pe	.0025		.0038
147		Equiv. p	.0031		.0045
148	Ash	Analysi			
149		Mois	1.19		
150		Ash,	74.04		
151		Vola	2.19		
152		Fixe	22.58		
153		Sul	.33		
154	Heat Balance	Heat pe	203000.		313250.
155			100.		100.
156		Heat pe	152000.		204783.
157			75.		65.9
158		Heat los	20200.		24367.
159			9.9		8.
160		Heat in	84300.		80791.
161			41.5		27.3
162		Heat in	3620.		4746.
163			1.8		1.4
164		Heat ≡	41250.		42383.
165			20.3		14.3
166		Heat ≡	19000.		15908.
167			9.4		5.4
168		Radiatio	7200.		102817.
169			3.8		30.
171		Heat lo	11190.		35147.
171			1.82		4.11
171.1		Heat los	23400.		28733.
171.2			11.5		9.6

	Date, Apr.		16.	17.	18.	19.	20.	21.	Totals	Average
138	St'd gas produced, cu. ft.	Per lb. coal consumed in producer.	74.3	71.5	67.8	78.8	67.4	77.1		72.8
139		Per lb. dry coal.								
140		Per lb. combustible.								
141		Per lb. equiv. coal used by plant.								
142		Per lb. equiv. comb. used by plant.								
143	Coal per H.P. hr.	Per B.H.P. hr., lbs.	1.94	1.76	1.33	1.4	1.17	.945		1.43
144		Equiv. per B.H.P. hr. used by plant, lbs.	1.94	1.94	2.	1.51	1.46	1.17		1.66
145	Cost of Coal	Cost per 2000 lbs. at plant, $	5.35	5.35	5.35	5.35	5.35	5.35		5.35
146		Cost per B.H.P. hr., $	.0052	.0047	.0036	.0037	.0031	.0025		.0038
147		Equiv. per B.H.P. hr. used by plant, $	.0052	.0052	.0053	.0040	.0039	.0031		.0045
148	Ash	Analysis: (Air dried)								
149		Moisture, %	1.49	1.49	1.49	1.19	1.19	1.19		
150		Ash, %	47.79	47.79	47.79	74.04	74.04	74.04		
151		Volatile, %	1.05	1.05	1.05	2.19	2.19	2.19		
152		Fixed Carbon, %	49.69	49.69	49.69	22.58	22.58	22.58		
153		Sulphur, %	.3	.3	.3	.33	.33	.33		
154	Heat Balance	Heat per hr. in coal, B.t.u.	396000.	390000.	286500.	326500.	277500.	203000.		313250.
155		%	100.	100.	100.	100.	100.	100.		100.
156		Heat per hr. in gas, B.t.u.	256000.	244100.	161700.	231900.	183000.	152000.		204783.
157		%	64.7	62.5	56.5	71.	66.	75.		65.9
158		Heat lost between prod. and eng., B.t.u.	24500.	25400.	16800.	35200.	24100.	20200.		24367.
159		%	6.2	6.5	5.9	10.8	8.7	9.9		8.
160		Heat in jacket water, B.t.u.	78500.	81700.	77600.	77800.	84850.	84300.		80791.
161		%	19.8	21.	27.1	23.8	30.6	41.5		27.3
162		Heat in exhaust gases, B.t.u.	5900.	5580.	3720.	5130.	4525.	3620.		4746.
163		%	.7	1.4	1.3	1.6	1.6	1.8		1.4
164		Heat ≡ useful work, B.t.u.	39200.	42500.	41250.	44800.	45300.	41250.		42383.
165		%	9.9	10.9	14.4	13.7	16.3	20.3		14.3
166		Heat ≡ friction, B.t.u.	16750.	17250.	12200.	15500.	14750.	19000.		15908.
167		%	4.2	4.4	4.3	4.7	5.3	9.4		5.4
168		Radiation and unaccounted for, B.t.u.	177000.	162000.	95500.	113500.	61700.	7200.		102817.
169		%	44.5	41.5	33.3	34.8	22.2	3.8		30.
171		Heat lost in refuse, B.t.u.	31000.	63000.	83300.	11200.	11190.	11190.		35147.
171		%	7.83	6.18	3.44	2.92	2.49	1.82		4.11
171.1		Heat lost in Heater, B.t.u.	27250.	31750.	29600.	24950.	35450.	23400.		28733.
171.2		%	6.9	8.1	10.3	7.7	12.8	11.5		9.6

	Date, Apr., 190		Totals	Average
172		A		
173				7.2
174	Gas			18.3
175	leaving			.1
176	producer			8.2
177				8.
178				58.
179	Temp. water			59.5
180	Temp. water l			151.
181	Temp. Atmos			78.2
182		In		.7
183	Manometer	At		
184		Er		
185	Readings.	Pr		
186		Ex		
187		To	1230.	
188	Fuel used	Dr	1200.	
189	in actual-	Co	1087.	
190	ly produc-	Co		23.6
191	ing power.	Dr		23.1
192	(i.e. fuel	Co		20.9
193	less stand-	To	945.6	
194	by loss)	Co		18.2
195		B.		313250.
196	Grate Effic			

*

	Date, Apr., 1906.		16.	17.	18.	19.	20.	21.	Totals	Average
172	Gas leaving producer	Analysis by vol. %								
173		CO_2	7.8	5.7	7.6	6.2	6.1	9.8		7.2
174		CO	18.7	20.2	18.1	21.	19.2	12.5		18.3
175		O	.15	.1	.0	.1	.15	.1		.1
176		CH_4	5.8	7.4	6.7	5.8	10.5	12.8		8.2
177		H	3.8	4.7	9.	14.0	8.3	8.0		8.
178		N	62.05	61.9	58.8	52.9	55.7	56.8		58.
179	Temp. water entering exh'st heater, F°		59.	59.5	61.	*59.5	*59.5	*59.5		59.5
180	Temp. water leaving exh'st heater, F°		153.	149.5	152.	*150.	*150.	*150.0		151.
181	Temp. Atmosphere, F°		71.	78.3	80.	80.	80.	80.		78.2
182	Manometer Readings.	In Air tank, Ins. of Water.	.7	.7	.7	.7	.7	.7		.7
183		At engine gas valve, Ins. Water	6.0	1.2	1.2	1.2	1.2	1.2		
184		Engine side of Scrubber, Ins. Water.	1.2	1.2	1.2	1.2	1.2	1.2		
185		Producer side of Scrubber, Ins. Wat.	.9	.9	.9	.9	.9	.9		
186		Exh'st gas exit of heater, Ins. Hg.	3.3	3.3	3.3	3.3	3.3	3.3		
187	Fuel used in actually producing power. (i.e. fuel less stand-by loss)	Total Coal per day as fired, lbs.	256.	264.8	186.	221.	194.5	107.5	1230.	
188		Dry Coal per day, lbs.	250.	258.5	181.9	216.	190.	105.	1200.	
189		Combustible per day, lbs	226.	233.9	164.1	195.1	171.8	95.	1087.	
190		Coal per hr. as fired, lbs.	29.8	29.4	21.6	24.6	20.9	15.3		23.6
191		Dry coal per hr., lbs.	29.1	28.8	21.1	24.	20.4	15.		23.1
192		Combustible per hr. lbs.	26.3	26.0	19.1	21.7	18.5	13.6		20.9
193		Total Carbon gasified per day, lbs.	200.6	189.	126.2	182.	160.	87.8	945.6	
194		Carbon gasified per. hr. lbs.	23.3	21.	14.7	20.2	17.2	12.5		18.2
195		B.t.u. per hr. in coal.	396000.	390000.	286500.	326500.	277500.	203000.		313250.
196	Grate Efficiency									

*Approximate; estimated

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